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**U. S. NAVAL AVIONICS FACILITY
INDIANAPOLIS, INDIANA**

TECHNICAL REPORT



U. S. N A V A L A V I O N I C S F A C I L I T Y
Indianapolis, Indiana

TECHNICAL REPORT

RESEARCH, ENGINEERING & TECHNICAL EVALUATION
DEPARTMENTS

Report Number TR-92

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PRINTED WIRING BOARDS, DIELECTRIC
STRENGTH OF

(DOD Project No. X999-0028)

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NOTICE

Technical Report No. TR-92 was formerly assigned the number "Materials Report No. 59". The former number may have been referenced on other documents. However, by the time this report was actually issued, the numbering system had been changed, and the report was issued as Technical Report No. TR-92.

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PREFACE

The purpose of this report is to present corona and breakdown voltage information, for use in the design of printed wiring boards for high altitude applications. These data were intended as background information for the conductor spacing recommendations in MIL-STD-275A.

The complete mass of raw data is published in this report, in addition to the recommended conductor spacings, because of repetitive requests by design engineers who prefer to review the raw data and set their own safety factors for each particular design application. For all others, the MIL-STD-275 conductor spacing tables, which include generous safety factors, are recommended.

ABSTRACT

This report establishes recommended spacings between the conductors on printed wiring boards. The corona discharge and dielectric breakdown voltages were measured for each of ten different spacings: .010, .015, .022, .025, .032, .062, .093, .125, .187, and .250 inches. The conditions of the test were based on parameters from MIL-STD-446 and MIL-E-5400. The tests are summarized as follows:

ALTITUDE FEET	RELATIVE HUMIDITY	TEMPERATURE °C (°F)	SPECIMEN MATERIALS	REF. MTR NO.
Sea level	Room humidity	Room temperature	epoxy	14-57
Sea level	90%	21°C (70°F)	epoxy	81-59
10,000	91%	125°C (257°F)	epoxy & phenolic	-
50,000	90%	Room temperature	epoxy	14-57
50,000	90%	21°C (70°F)	epoxy	81-59
50,000	91%	125°C (257°F)	epoxy & phenolic	-
50,000	100% with condensation	55°C (131°F)	epoxy & phenolic	50-60
70,000	90%	21°C (70°F)	epoxy	81-59
70,000	100% with condensation	71°C (160°F)	epoxy & phenolic	50-60
80,000	room humidity	150°C (302°F)	epoxy	93-61
80,000	90%	21°C (70°F)	epoxy	81-59
80,000	91%	125°C (257°F)	epoxy & phenolic	50-60
80,000	100% with condensation	95°C (203°F)	epoxy & phenolic	50-60
100,000	91%	125°C (257°F)	epoxy & phenolic	50-60

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I. CONCLUSIONS

Corona information can be obtained accurately and reproducibly, by the procedures outlined in this report. However, the MIL-STD-446 design parameters specify nonequilibrium conditions, such as high altitude plus high temperature plus high humidity, because these seemingly impossible conditions are present in airborne military electronic equipment. Therefore, it is concluded that corona tests are valid, only if all of the required conditions are met; extrapolation is of doubtful value.

The raw data in this report represent the conditions where failure is sure to occur. Because printed wiring boards should be designed so as not to fail, it is concluded that adequate safety factors should be used.

The test specimens were burnished with fine steel wool prior to corona testing to remove all points and sharp edges which could serve as focal points for corona. However, actual printed wiring boards will not be burnished, and several points and sharp edges may be present. No two printed wiring boards will be alike, in this respect, therefore it is concluded that the safety factor should be sufficiently large to cover this feature.

II. RECOMMENDATIONS

The recommended conductor spacings are listed below. These values, which include safety factors, were published in MIL-STD-275A.

The minimum recommended spacing between conductors, for power up to and including 50 watts, should be as indicated in the table below. For applications where secondary circuit protection is provided in the form of fuses, circuit breakers, etc., and where the normal operating power is greater than 50 watts but does not exceed 2000 watts, the minimum spacing between conductors shall be twice that indicated in the tables below.

Recommended conductor spacing for uncoated boards from sea level to 10,000 feet inclusive:

Voltage between conductors (DC or AC peak volts)	Minimum Spacing	
	inches	
	Grade A	Grade B
0 to 50	.015	.080
51 to 150	.026	.080
151 to 300	.062	.125
301 to 500	.125	.300

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The recommended minimum spacing between conductors on uncoated boards should be in accordance with the table below when the boards are subjected to reduced pressure equivalent to altitudes greater than 10,000 feet with powers up to and including 50 watts for normal service environments. Where the board will be directly exposed to severe contamination, additional spacing shall be provided based on the particular application or coated boards shall be used.

Recommended conductor spacings, for uncoated boards, for use above 10,000 feet:

Voltage between conductors (DC or AC peak volts)	Minimum Spacing inches
0 to 50	.026
51 to 100	.062
101 to 170	.125
171 to 250	.250
251 to 500	.500

III. BACKGROUND INFORMATION

The measurement of corona discharge voltages, for various conductor spacings, at various altitudes and at various humidities, was performed by the U. S. Naval Avionics Facility, Indianapolis, for the purpose of obtaining data for publication in MIL-STD-275A.

The design parameters, such as altitude, temperature, and relative humidity were selected from MIL-STD-446 and MIL-E-5400. Ten different conductor spacings were selected.

IV. DESCRIPTION AND DISCUSSION

A. PROCEDURES

1. Introduction

Inasmuch as this report is a compilation of several separate tests, which were performed at different times with different apparatus, each procedure will be discussed separately. In general, however, each test involved three common features:

a. Placing the specimens in the desired atmosphere of vacuum, temperature, and relative humidity.

b. Connecting the specimens to a power supply, meters, and

gradually increasing the potential until corona occurred. Corona was detected on an oscilloscope. See Figure 1.

c. Measuring the corona discharge voltage at the instant it occurs.

2. Specimen Preparation

All of the larger specimens were prepared by screen process printing. The two smaller specimens, AV 1703 and AV 1704, were prepared photographically, using Kodak Photo Resist. The specimens were etched in ammonium persulfate solution and were visually inspected using 24 X magnification. Before the corona test, the specimens were rubbed vigorously with fine steel wool in the lengthwise direction and degreased with clean liquid trichloroethylene. The steel wool removed tiny points and sharp edges which could serve as focal points for corona.

3. Procedure for 90% RH

The procedure is as follows:

a. A glass desiccator jar was used to hold three test specimens under conditions of 90% relative humidity at 21°C (70°F) and at the various altitude pressures. A saturated solution of potassium nitrate in the bottom of the jar was used to obtain the humidity. The air pressure used for simulating the various altitudes was obtained from the Tenny Altitude Conversion Table.

b. Electrical connections were made inside the jar by potting wires through the desiccator lid. Also potted into the lid was a glass tube branching to a vacuum pump and a dial type vacuum gage. The relative humidity was measured with an Aminco Electric Hydrometer.

c. Three specimens of the same part number and the hydrometer sensing element were soldered to the wires in the desiccator lid. The jar was evacuated to the desired pressure. The humidity was checked periodically until 90% RH was reached and testing was started.

d. The corona and breakdown voltages were determined by using a Hi-Pot (High Voltage Tester, Industrial Instruments, Inc.) equipped with an auxiliary AC voltmeter having a range of 1,000 volts. An oscilloscope was used to determine when corona started. The electrical circuit is shown in Figure 1. Each specimen was tested individually, first for corona, and then breakdown. Voltage was slowly increased until a blue glow (corona) was observed between the copper lines, or the waveform on the oscilloscope became distorted. The oscilloscope was then disconnected and the voltage was increased until breakdown, indicated by the circuit breaker.

4. Procedure for 100% RH

a. The apparatus listed and shown in several prints was set up to determine the dielectric strength of various printed circuit boards.

b. The prints show how the apparatus was used and how the boards were placed in the stainless steel bell jar. One container, a large Pyrex dish, was placed below the specimens; the other, a stainless steel container, was placed above the specimens. It rested on a shield that contained the heaters. Water was placed in both to obtain the humidity.

c. The stainless steel bell jar was seated and heated until the desired temperature and humidity was reached. Then the system was opened to the pumps and the desired altitude was simulated. The tests were completed with the results shown in the tables.

B. SPECIMENS

1. Sizes

The following table lists the specimens by number, conductor spacing, and conductor width.

PART NO.	CONDUCTOR SPACING	CONDUCTOR WIDTH
AV 1703	.010	.010
AV 1704	.015	.015
AV 1705	.022	.022
AV 1706	.025	.025
AV 1707	.032	.032
AV 408	.062	.062
AV 409	.093	.093
AV 410	.125	.125
AV 411	.187	.187
AV 412	.250	.250

2. Materials

Printed wiring boards are ordinarily made of either paper phenolic laminate or glass epoxy laminate. Specimens for these tests were made from each material. None of the specimens was coated with varnish prior to testing.

a. Phenolic. MIL-P-13949B, FL-PP-062-C-2/0

b. Epoxy. MIL-P-13949B, FL-GE-062-C-2/0

C. APPARATUS

1. A Screen Process Printing Press (BuWeps Dwg. No. DS 643)

The ink resist was Naz-Dar No. 211.

2. Photographic Equipment for the Kodak Photo Resist Process

This included a lamp for exposure, a rotary turntable for drying the KPR, and a small trichloroethylene vapor degreaser for developing the KPR.

3. Etching Equipment

A bubble etcher was used (AV 1633) with an etching solution consisting of:

ammonium persulfate 298 gm/l (2.5 lb/gal)

66° Be sulfuric acid 15.5 ml/l (59 ml/gal)

The temperature was 43°C (110°F).

The air pressure was 10 psig, and bubble agitation was uniformly distributed.

4. Microscope

Spencer Serial No. 199211, 24 X, binocular

5. An 18" stainless steel bell jar, pumps, etc., approximately (13 cubic feet per min.)

6. "i-Pot (Industrial Instruments, Inc.)

7. Variac - 10 amps (Superior Electric Co.)

8. Specimen holder, AV 2806

9. Infrared Heater. (special)

10. Two containers for Water

11. Potentiometer (L & N #1160124)

12. Barometer, mercurial, range 1,000 to 200,000 feet (Hass Bro. Instrument Co., U.S.N. BuOrd 015405)

13. Oscilloscope

14. Hydrometer (Aminco)

D. EXPLANATION OF 100% RH

MIL-STD-446 requires 100% relative humidity with condensation. In this test it was possible to get a momentary 100% RH with profuse condensation, but equilibrium was reached faster than the hydrometer could function; so the actual measured values never exceeded 91% RH. The data is reported as "100% RH with condensation" because 100% RH was the actual condition at the moment of corona.

MIL-STD-446 requires 100% RH with condensation at 125°C at all altitudes. Condensation is nearly impossible at 80,000 feet altitude, and is completely impossible at altitudes higher than 80,000 feet. Therefore, the data in this report are recommended for all designs which must comply with MIL-STD-446 at all altitudes up to and including 100,000 feet.

APPENDIX

A. TABLES

1. Corona discharge voltages for various altitudes.

B. FIGURES

1. Schematic - Sketch
2. Rack Assembly
3. Specimens
4. Specimens
5. Specimens

C. PHOTOGRAPHS

1. Test chamber after testing has been completed. (Notice the condensed moisture.)
2. Test chamber while operating.
3. Power supply and associated electrical measuring instruments.

Conductor Spacing	SEA LEVEL 90% RH 21°C (70°F) EPOXY SPECIMENS (See MTR 81-59)		SEA LEVEL ROOM CONDITIONS EPOXY SPECIMENS (See MTR 14-57)	
	CORONA DISCHARGE	BREAKDOWN	HI-POT SETTING AT BREAKDOWN 60 cycle AC	BREAKDOWN 60 cycle AC
inches	volts	volts	volts rms	volts rms
.010	none none none none	550 500 700 670	1400	1000 1400
		Avg 605		Avg 1200
.015	none none none	870 800 900	1400	1200 1200
		Avg 857		Avg 1200
.022	none none none	1300 1200 1100	1500	1300 1400
		Avg 1200		Avg 1350
.025	none none none	1300 1200 1200	1100	1600 1400
		Avg 1233		Avg 1500
.032	none none none	1280 1400 1300	1425	1500 1700
		Avg 1327		Avg 1600

Conductor Spacing	10,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS		10,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts	volts	volts
.010	400	400	440	440
	--	--	490	490
	--	--	580	580
	520	520	520	520
	580	580	560	650
	540	540	630	630
	Avg 510	Avg 510	Avg 537	Avg 552
.015	720	720	740	740
	--	--	700	750
	660	660	670	670
	--	--	630	680
	640	640	740	740
	750	750	--	750
	Avg 692	Avg 692	Avg 696	Avg 722
.022	920	920	600	600
	1160	1160	1000	1000
	1000	1000	800	800
	930	930	950	950
	840	840	850	850
	740	740	800	800
	Avg 932	Avg 932	Avg 833	Avg 833
.025	1140	1140	1000	1000
	1230	1230	1050	1050
	1100	1100	1100	1100
	800	800	1040	1040
	1100	1100	1000	1000
	1100	1100	1050	1050
	Avg 1078	Avg 1078	Avg 1040	Avg 1040
.032	1360	1360	1040	1040
	1100	1310	1160	1160
	1300	1300	1200	1200
	1150	1150	1050	1120
	1360	1360	1050	1050
	1150	1150	1060	1060
	Avg 1237	Avg 1272	Avg 1093	Avg 1105

Conductor Spacing	10,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS		10,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts	volts	volts
.062	1460 1000 1400 1400 1300 1350	1560 1000 1500 1400 1350 1400	1500 1550 1600 1500 1730 1600	1500 1740 1700 1580 1730 1600
	Avg 1318	Avg 1368	Avg 1580	Avg 1642
.093	1800 1810 -- 1750 1720 --	1800 1850 -- 1800 1720 	1660 1950 2030 2040 2140 	1950 2050 2030 2040 2140 2000
	Avg 1770	Avg 1792	Avg 1970	Avg 2035
.125	1350 2070 1650 1470 1250 1400	1350 2070 1700 1470 1250 1400	2000 2100 1800 2030 2100 1740	2400 2100 2200 2030 2100 1740
	Avg 1532	Avg 1540	Avg 1962	Avg 2095
.187	650 1300 -- -- 950 --	650 1300 -- -- 1050 	-- 3000 2200 2400 2100 1900	3000 3000 2200 2400 2100 1900
	Avg 967	Avg 1000	Avg 2320	Avg 2433
.250	1900 2140 1900 2200 1750 2200	1900 2140 2300 2200 1750 2200	-- 3500 2100 2700 2400 2510	2300 3500 2500 2700 2400 2510
	Avg 2015	Avg 2082	Avg 2642	Avg 2652

Conductor Spacing inches	50,000 FEET 90% RH ROOM TEMPERATURE EPOXY SPECIMENS (from MTR 14-57)		50,000 FEET 90% RH 21°C (70°F) EPOXY SPECIMENS (from MTR 81-59)	
	CORONA DISCHARGE volts	BREAKDOWN volts	CORONA DISCHARGE volts	BREAKDOWN volts
.010	320 330 340 320 330 330 Avg 328	330	310 320 320	400 410 420 Avg 410
.015	370 390 420 400 385 380 Avg 390	450 435	360 360 350	430 440 430 Avg 433
.022	390 440 490 490 430 490 Avg 455	480	370 350 370	450 460 460 Avg 457
.025	480 500 490 480 500 Avg 490	480	390 370 370	450 450 450 Avg 450
.032	540 510 510 490 520 490 Avg 510	500	400 380 400	410 450 440 Avg 433

Conductor Spacing inches	50,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS		50,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
	volts	volts	volts	volts
.010	290	---	350	520
	---	---	350	450
	340	460	300	480
	340	440	340	490
	350	480	340	430
	330	440	350	470
	Avg 330	Avg 455	Avg 338	Avg 473
.015	350	490	360	460
	330	510	360	470
	400	470	340	470
	400	460	350	520
	400	480	310	500
	390	460	340	480
	Avg 378	Avg 478	Avg 343	Avg 483
.022	380	530	---	---
	500	800	400	560
	510	800	450	550
	480	500	450	570
	450	500	450	580
	470	740	480	520
	Avg 465	Avg 645	Avg 446	Avg 556
.025	420	540	530	550
	500	760	450	500
	510	840	400	550
	490	690	490	570
	470	630	480	590
	470	600	470	590
	Avg 477	Avg 677	Avg 470	Avg 558
.032	450	510	500	580
	550	820	460	530
	400	560	420	570
	520	580	470	580
	---	---	480	590
	520	740	470	570
	Avg 488	Avg 642	Avg 467	Avg 570

Conductor Spacing inches	50,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS		50,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE volts	BREAKDOWN volts	CORONA DISCHARGE volts	BREAKDOWN volts
.062	600 560 650 640 740 610 Avg 633	720 690 670 720 770 770 Avg 723	730 690 610 640 640 650 Avg 660	730 690 660 640 660 650 Avg 672
.093	700 850 810 750 950 630 Avg 782	870 850 860 820 950 860 Avg 868	930 880 730 730 770 800 Avg 807	930 900 780 800 770 800 Avg 830
.125	1090 830 820 --- --- 850 Avg 897	1140 1060 1050 950 1110 960 Avg 1045	1020 1100 1000 1030 950 1000 Avg 1017	1160 1140 1050 1030 1050 1050 Avg 1080
.187	1100 900 --- --- 950 650 Avg 900	1200 1090 950 1070 1050 650 Avg 1002	1250 1240 1140 1150 1240 1190 Avg 1202	1540 1280 1260 1250 1240 1190 Avg 1293
.250	1200 900 750 --- 1000 900 Avg 950	1360 1190 1050 1200 1100 1300 Avg 1200	1600 1400 1350 1400 1480 1450 Avg 1447	1600 1450 1450 1450 1480 1450 Avg 1480

Conductor Spacing	50,000 FEET 100% RH WITH CONDENSATION 55°C (131°F) EPOXY SPECIMENS (See MTR 50-60)		50,000 FEET 100% RH WITH CONDENSATION 55°C (131°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts	volts	volts
.010	---	450	---	---
	420	420	300	510
	---	---	250	500
	350	400	320	630
	400	440	340	460
	300	340	320	450
	Avg 377	Avg 410	Avg 306	Avg 510
.015	---	500	400	480
	---	390	340	530
	---	---	400	500
	400	500	280	490
	420	460	370	470
	400	500	350	490
	Avg 407	Avg 470	Avg 340	Avg 493
.022	400	500	450	520
	460	---	320	530
	400	400	410	520
	410	420	430	490
	480	440	410	480
	420	480	420	500
	Avg 428	Avg 448	Avg 407	Avg 507
.025	460	500	470	530
	450	450	340	530
	420	---	440	540
	420	480	720	720
	440	440	480	500
	---	---	420	510
	Avg 438	Avg 467	Avg 478	Avg 555
.032	420	430	470	620
	520	---	330	530
	500	---	480	540
	510	510	500	500
	500	500	470	500
	480	570	480	530
	Avg 488	Avg 502	Avg 455	Avg 537

Conductor Spacing	50,000 FEET 100% RH WITH CONDENSATION 55°C (131°F) EPOXY SPECIMENS (See MTR 50-60)		50,000 FEET 100% RH WITH CONDENSATION 55°C (131°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts	volts	volts
.062	590 610 700 660 720 680 Avg 660	610 --- --- 700 700 680 Avg 672	620 400 620 700 630 600 Avg 595	700 580 700 760 700 660 Avg 683
.093	800 820 820 800 880 600 Avg 787	850 --- --- 850 --- 620 Avg 773	750 440 820 800 750 800 Avg 727	900 580 820 900 880 890 Avg 828
.125	800 900 900 900 800 800 Avg 850	820 --- --- --- 800 820 Avg 813	1100 600 900 960 1000 850 Avg 902	1100 690 900 1050 1000 970 Avg 952
.187	1000 1200 1150 1000 1200 950 Avg 1083	1030 --- --- --- --- 960 Avg 995	1050 720 1000 1000 1050 1000 Avg 970	1050 720 1100 1130 1100 1050 Avg 1025
.250	1050 600 1400 1400 1300 1300 Avg 1175	1050 --- --- --- --- 1300 Avg 1175	1450 720 900 900 1350 1250 Avg 1095	1450 720 900 900 1350 1300 Avg 1103

Conductor Spacing	70,000 FEET 90% RH 21°C (70°F) EPOXY SPECIMENS (See MTR 81-59)	
	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts
.010	320 315 320 320 310	440 440 440 440 430
	Avg 317	Avg 438
.015	320 350 360 350 360 360	440 480 460 490 490 490
	Avg 350	Avg 472
.022	360 360 360	460 480 440
	Avg 360	Avg 460
.025	370 380 380 350 370 350	480 480 470 460 460 470
	Avg 367	Avg 470
.032	380 350 400 380 390 380	460 460 460 470 490 480
	Avg 380	Avg 470

Conductor Spacing inches	70,000 FEET 100% RH WITH CONDENSATION 71°C (160°F) EPOXY SPECIMENS (See MTR 50-60)		70,000 FEET 100% RH WITH CONDENSATION 71°C (160°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE volts	BREAKDOWN volts	CORONA DISCHARGE volts	BREAKDOWN volts
.010	300 320 340 320 340 300 Avg 320	350 330 400 400 -- 320 Avg 360	300 320 300 320 300 300 Avg 307	530 520 540 530 540 530 Avg 532
.015	320 340 360 320 380 380 Avg 350	-- 480 500 480 480 390 Avg 466	300 320 310 310 320 300 Avg 310	540 530 520 530 530 500 Avg 525
.022	340 400 340 360 380 380 Avg 367	-- 420 460 480 460 440 Avg 452	280 320 320 310 320 320 Avg 312	520 520 520 530 520 520 Avg 522
.025	360 420 350 380 380 380 Avg 378	-- 480 480 480 480 440 Avg 472	320 320 280 330 340 330 Avg 320	520 520 520 520 520 520 Avg 520
.032	240 440 400 410 400 400 Avg 382	-- 460 490 480 480 440 Avg 470	340 340 310 360 370 340 Avg 343	510 530 520 530 540 530 Avg 527

Conductor Spacing	70,000 FEET 100% RH WITH CONDENSATION 71°C (160°F) EPOXY SPECIMENS (See MTR 50-60)		70,000 FEET 100% RH WITH CONDENSATION 71°C (160°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts	volts	volts
.062	400 460 480 500 540 440 <u>Avg 470</u>	-- 520 520 540 -- -- <u>Avg 527</u>	400 450 470 470 460 460 <u>Avg 452</u>	550 550 560 570 570 560 <u>Avg 560</u>
.093	520 480 500 600 600 480 <u>Avg 530</u>	-- 520 580 640 620 520 <u>Avg 576</u>	520 560 520 540 520 540 <u>Avg 533</u>	580 580 590 590 600 600 <u>Avg 590</u>
.125	-- 560 560 600 660 560 <u>Avg 588</u>	-- -- 640 -- 700 600 <u>Avg 647</u>	590 680 670 560 600 600 <u>Avg 617</u>	620 680 670 620 640 630 <u>Avg 643</u>
.187	-- 600 580 650 750 600 <u>Avg 636</u>	-- -- 600 700 800 -- <u>Avg 700</u>	570 760 670 690 710 680 <u>Avg 680</u>	600 820 670 740 750 740 <u>Avg 720</u>
.250	-- 800 600 900 1000 700 <u>Avg 800</u>	-- -- -- -- -- -- <u>Avg 863</u>	810 900 970 800 890 810 <u>Avg 872</u>	810 900 970 800 900 850 <u>Avg 872</u>

Conductor Spacing inches	80,000 FEET DRY 150°C (302°F) EPOXY SPECIMENS (See MTR 93-61)		80,000 FEET 90% RH 21°C (70°F) EPOXY SPECIMENS (See MTR 81-59)	
	CORONA DISCHARGE volts	BREAKDOWN volts	CORONA DISCHARGE volts	BREAKDOWN volts
.010	300 300 300 300 325 Avg 305	not measured	330 330 320 320 310 310 Avg 320	350 340 350 320 340 320 Avg 337
.015	300 325 300 325 325 Avg 315	not measured	320 330 340 340 340 350 Avg 337	400 420 420 350 350 350 Avg 382
.022	300 325 325 300 350 Avg 320	not measured	315 340 330 360 360 Avg 341	400 370 390 410 390 Avg 392
.025	325 350 325 350 350 Avg 340	not measured	370 360 360 360 370 360 Avg 363	410 390 380 400 390 380 Avg 392
.032	350 350 350 375 375 Avg 360	not measured	360 380 390 360 350 380 Avg 370	400 380 390 390 400 380 Avg 390

Conductor Spacing	80,000 FEET DRY 150°C (302°F) EPOXY SPECIMENS (See MTR 93-61)	
	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts
.062	425 425 450 425 450 Avg 435	not measured
.093	525 475 500 475 480 Avg 491	not measured
.125	500 525 500 500 550 Avg 515	hot measured
.187	650 625 650 700 700 Avg 665	not measured
.250	800 700 700 800 800 Avg 760	not measured

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Conductor Spacing inches	80,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS (See MTR 50-60)		80,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE volts	BREAKDOWN volts	CORONA DISCHARGE volts	BREAKDOWN volts
.010	290 300 230 300 290 270 Avg 280	490 340 340 380 370 270 Avg 365	300 300 340 300 290 310 Avg 307	550 550 570 560 570 550 Avg 558
.015	300 300 280 300 280 270 Avg 288	380 360 380 420 590 360 Avg 415	290 310 300 300 300 310 Avg 302	550 530 580 580 540 560 Avg 557
.022	300 300 300 340 270 270 Avg 297	450 430 400 500 570 510 Avg 477	290 300 330 320 290 320 Avg 308	540 530 590 580 550 660 Avg 575
.025	280 300 290 350 270 280 Avg 295	490 510 520 500 440 390 Avg 475	290 340 310 -- 330 -- Avg 317	540 530 590 760 650 -- Avg 614
.032	280 280 280 350 290 280 Avg 293	450 490 490 510 460 450 Avg 475	290 330 330 330 300 310 Avg 315	550 520 570 540 550 550 Avg 547

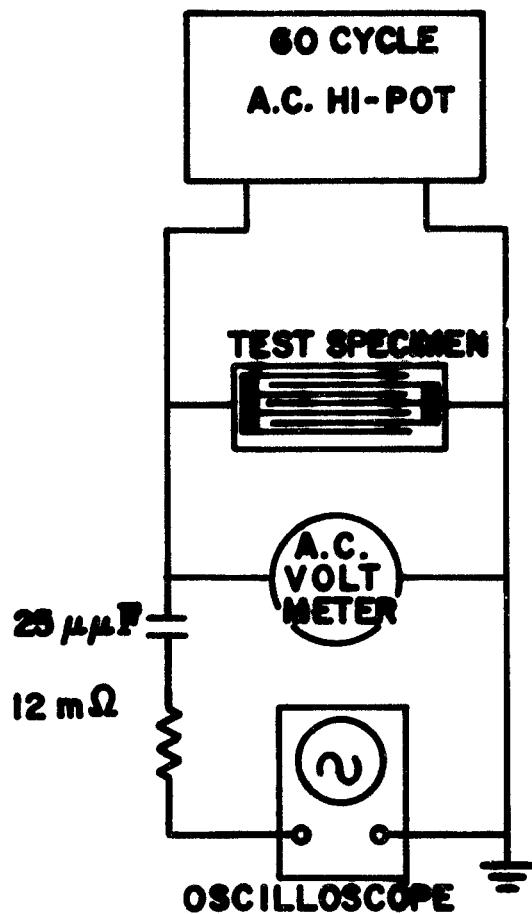
Conductor Spacing inches	80,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS (See MTR 50-60)		80,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS (See MTR 50-60)	
	CORONA DISCHARGE volts	BREAKDOWN volts	CORONA DISCHARGE volts	BREAKDOWN volts
.062	400 370 360 320 300 300 Avg 342	470 490 500 480 490 500 Avg 488	330 380 400 400 350 400 Avg 377	540 550 530 550 550 560 Avg 547
.093	440 370 350 340 310 320 Avg 355	480 510 510 500 500 510 Avg 502	350 380 430 420 430 470 Avg 413	570 570 550 560 570 580 Avg 567
.125	380 420 390 340 320 360 Avg 368	520 550 550 500 520 570 Avg 535	440 490 510 490 540 500 Avg 495	600 600 570 590 590 610 Avg 593
.187	400 480 400 360 330 500 Avg 412	550 580 580 560 580 590 Avg 573	480 560 510 510 570 600 Avg 538	640 650 610 610 660 670 Avg 640
.250	500 500 400 400 400 580 Avg 463	590 610 520 560 570 660 Avg 585	570 650 650 620 650 650 Avg 632	660 650 700 630 710 700 Avg 675

Conductor Spacing	80,000 FEET 100% RH WITH CONDENSATION 95°C (203°F) EPOXY SPECIMENS (See MTR 50-60)		80,000 FEET 100% RH WITH CONDENSATION 95°C (203°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts	volts	volts
.010	300 300 290 300 280 170 Avg 273	400 410 560 520 360 --- Avg 450	310 290 300 300 300 320 Avg 303	600 760 560 580 550 560 Avg 602
.015	300 290 300 290 290 300 Avg 295	400 480 530 440 340 490 Avg 447	310 270 280 250 290 330 Avg 288	570 560 560 520 550 570 Avg 555
.022	320 300 290 290 290 320 Avg 302	540 480 490 480 500 490 Avg 497	340 300 310 330 370 320 Avg 328	520 560 530 510 600 650 Avg 562
.025	200 290 280 300 300 --- Avg 274	--- 490 470 480 470 --- Avg 477	310 290 300 430 330 320 Avg 330	510 530 530 560 650 610 Avg 565
.032	340 300 290 300 300 320 Avg 303	480 460 490 490 460 500 Avg 480	350 320 340 350 340 --- Avg 340	520 540 530 530 570 --- Avg 533

Conductor Spacing	80,000 FEET 100% RH WITH CONDENSATION 95°C (203°F) EPOXY SPECIMENS (See MTR 50-60)		80,000 FEET 100% RH WITH CONDENSATION 95°C (203°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE inches	BREAKDOWN volts	CORONA DISCHARGE volts	BREAKDOWN volts
.062	380 320 300 380 340 460 Avg 363	500 460 490 490 490 530 Avg 493	390 330 380 430 400 400 Avg 388	530 540 540 520 550 560 Avg 540
.093	540 350 400 380 400 510 Avg 430	--- 480 490 510 500 560 Avg 508	450 400 420 500 470 480 Avg 453	560 580 570 600 590 570 Avg 578
.125	520 400 400 400 450 530 Avg 450	580 510 560 530 540 580 Avg 550	540 560 510 550 550 540 Avg 542	580 590 610 590 600 610 Avg 597
.187	500 420 460 480 440 550 Avg 475	550 540 570 560 570 660 Avg 575	590 500 600 580 600 560 Avg 572	630 640 680 710 670 640 Avg 662
.250	400 540 600 520 500 650 Avg 535	450 560 680 590 580 1000 Avg 643	600 760 630 600 780 680 Avg 675	650 820 690 700 780 720 Avg 727

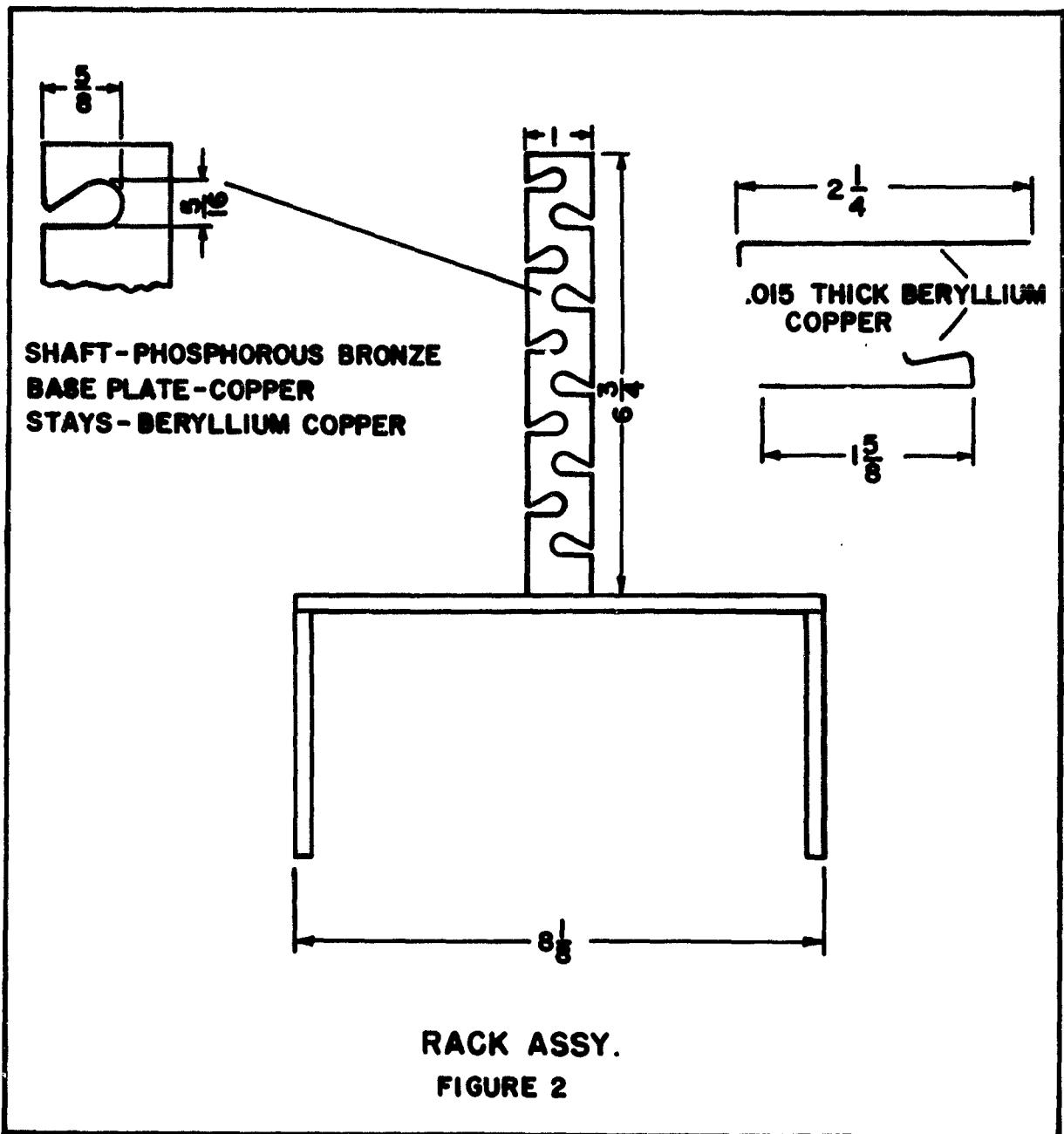
Conductor Spacing inches	100,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS (See NFR 50-60)		100,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
	volts	volts	volts	volts
.010	270	590	---	570
	300	590	280	660
	210	740	300	640
	210	580	320	700
	230	630	320	690
	280	1000	290	650
	Avg 250	Avg 688	Avg 302	Avg 652
.015	380	700	300	600
	300	600	---	740
	---	---	280	580
	320	580	300	630
	230	520	310	900
	230	520	300	800
	Avg 292	Avg 584	Avg 298	Avg 708
.022	270	440	290	630
	230	530	290	600
	220	470	280	570
	250	480	300	650
	230	500	300	670
	210	510	280	610
	Avg 235	Avg 488	Avg 290	Avg 622
.025	230	470	290	570
	200	520	270	530
	220	450	270	540
	230	460	300	580
	240	480	300	830
	210	490	310	710
	Avg 222	Avg 478	Avg 290	Avg 627
.032	240	430	280	580
	200	500	300	620
	230	460	270	570
	220	450	300	580
	230	480	300	930
	210	500	---	---
	Avg 222	Avg 470	Avg 290	Avg 656

Conductor Spacing inches	100,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS (See MTR 50-60)		100,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
	volts	volts	volts	volts
.062	290	460	320	530
	290	520	340	490
	300	440	280	500
	270	450	330	520
	230	460	330	520
	280	490	360	520
	Avg 277	Avg 470	Avg 327	Avg 513
.093	230	440	320	540
	310	490	360	510
	260	480	300	520
	300	470	360	500
	250	480	370	510
	240	490	400	520
	Avg 265	Avg 475	Avg 352	Avg 517
.125	260	460	360	530
	370	490	410	520
	370	490	350	530
	320	490	400	510
	360	500	390	520
	330	510	410	530
	Avg 335	Avg 490	Avg 387	Avg 523
.187	400	520	430	540
	350	500	420	560
	390	500	450	550
	360	530	410	550
	400	530	450	550
	340	530	490	580
	Avg 373	Avg 518	Avg 442	Avg 555
.250	500	560	420	550
	320	510	500	580
	410	520	470	580
	440	570	460	580
	450	560	400	580
	410	550	580	590
	Avg 422	Avg 545	Avg 472	Avg 577



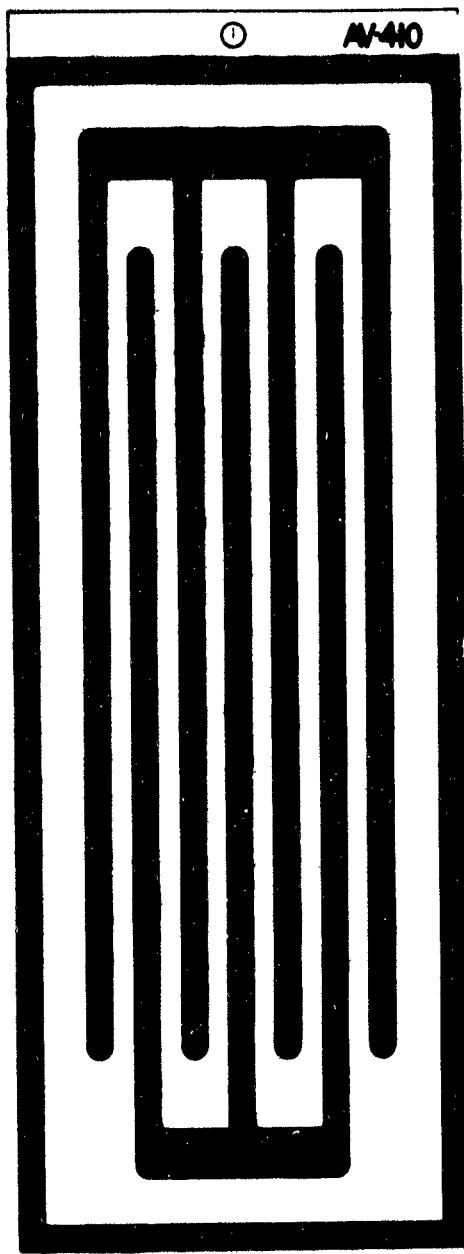
SCHEMATIC - SKETCH

FIGURE 1

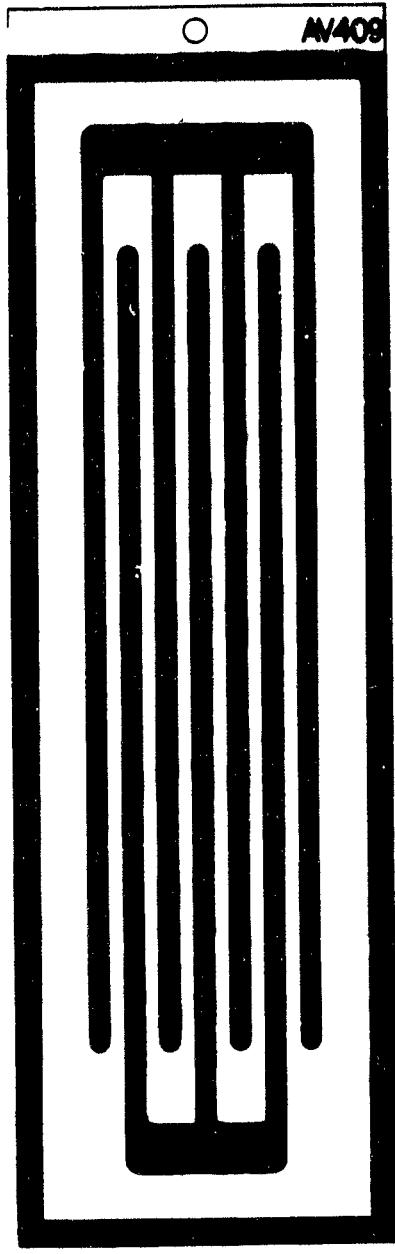


AV 1703	REM 14	
	.010 conductor spacing	.010 conductor width
AV 1704	REM 15	
	.015 conductor spacing	.015 conductor width
AV 1705	REM 16	
	.022 conductor spacing	.022 conductor width
AV 1706	REM 17	
	.025 conductor spacing	.025 conductor width
AV 1707	REM 18	
	.032 conductor spacing	.032 conductor width

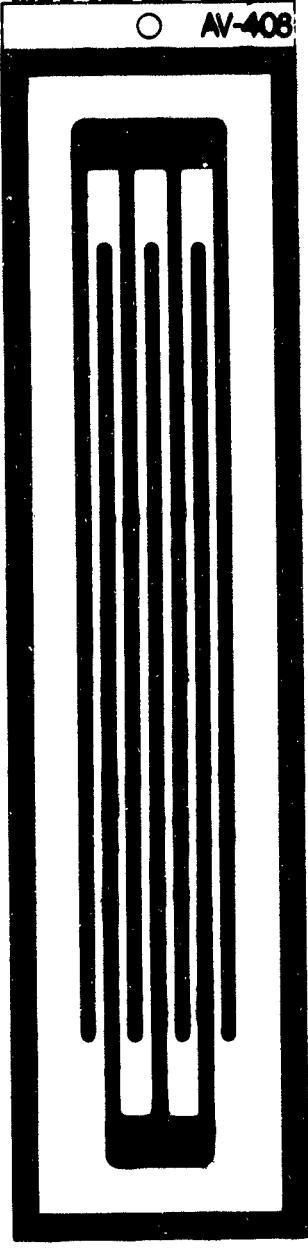
Figure 3.



.1250 conductor spacing
.1250 conductor width



.0937 conductor spacing
.0937 conductor width

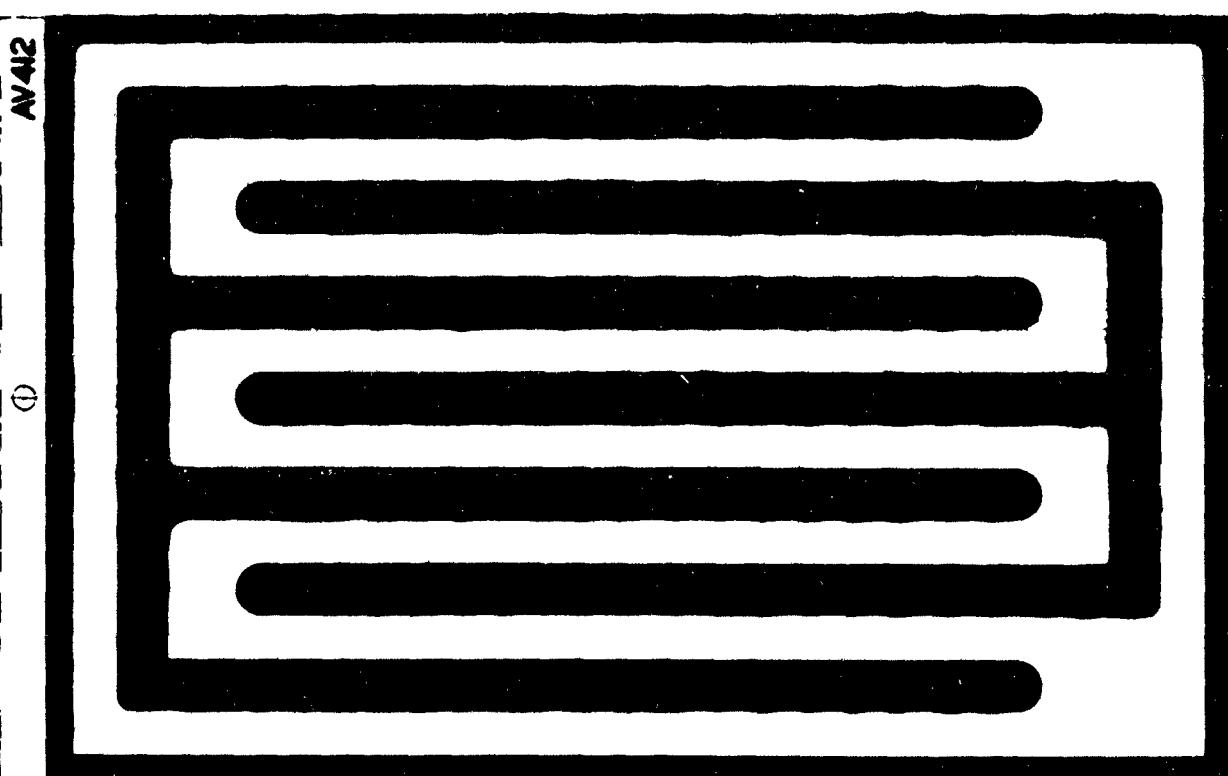
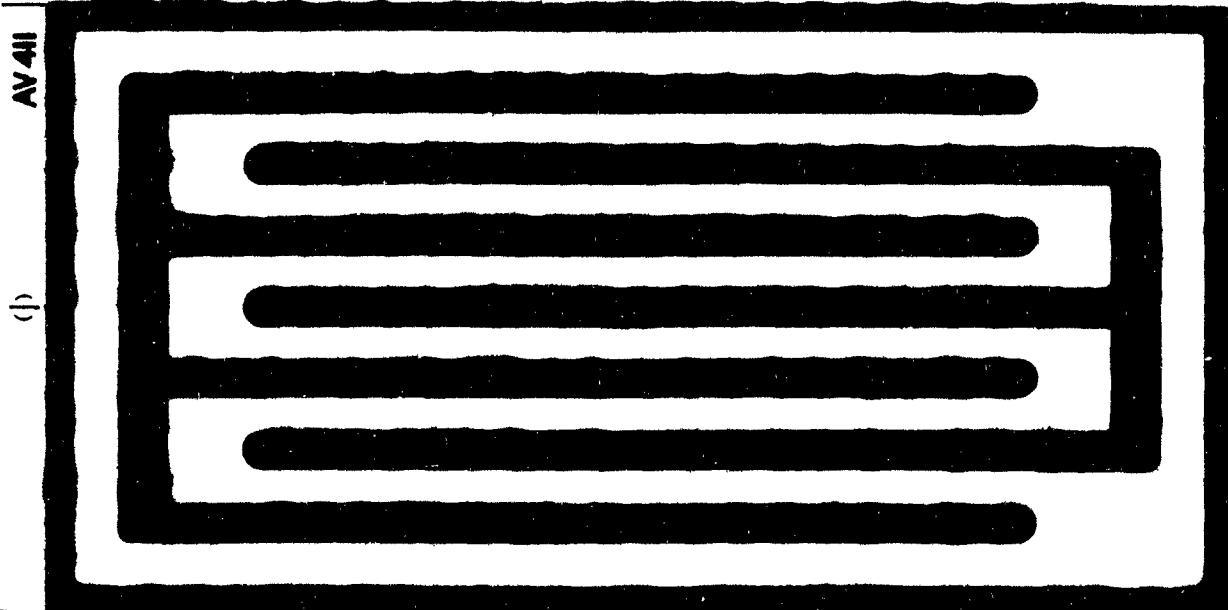


.0625 conductor spacing
.0625 conductor width

Figure 4.

.1875 conductor spacing

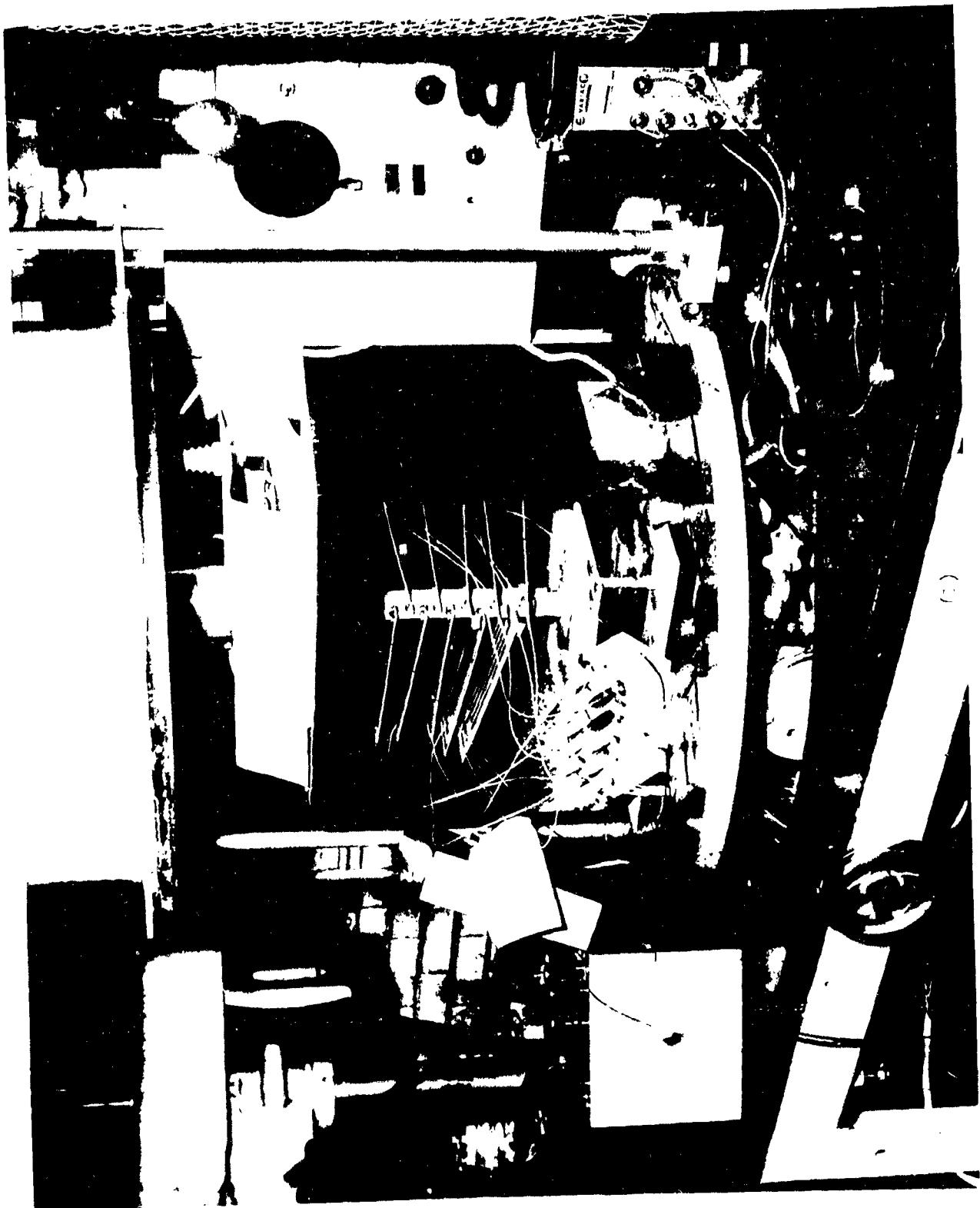
.1875 conductor width

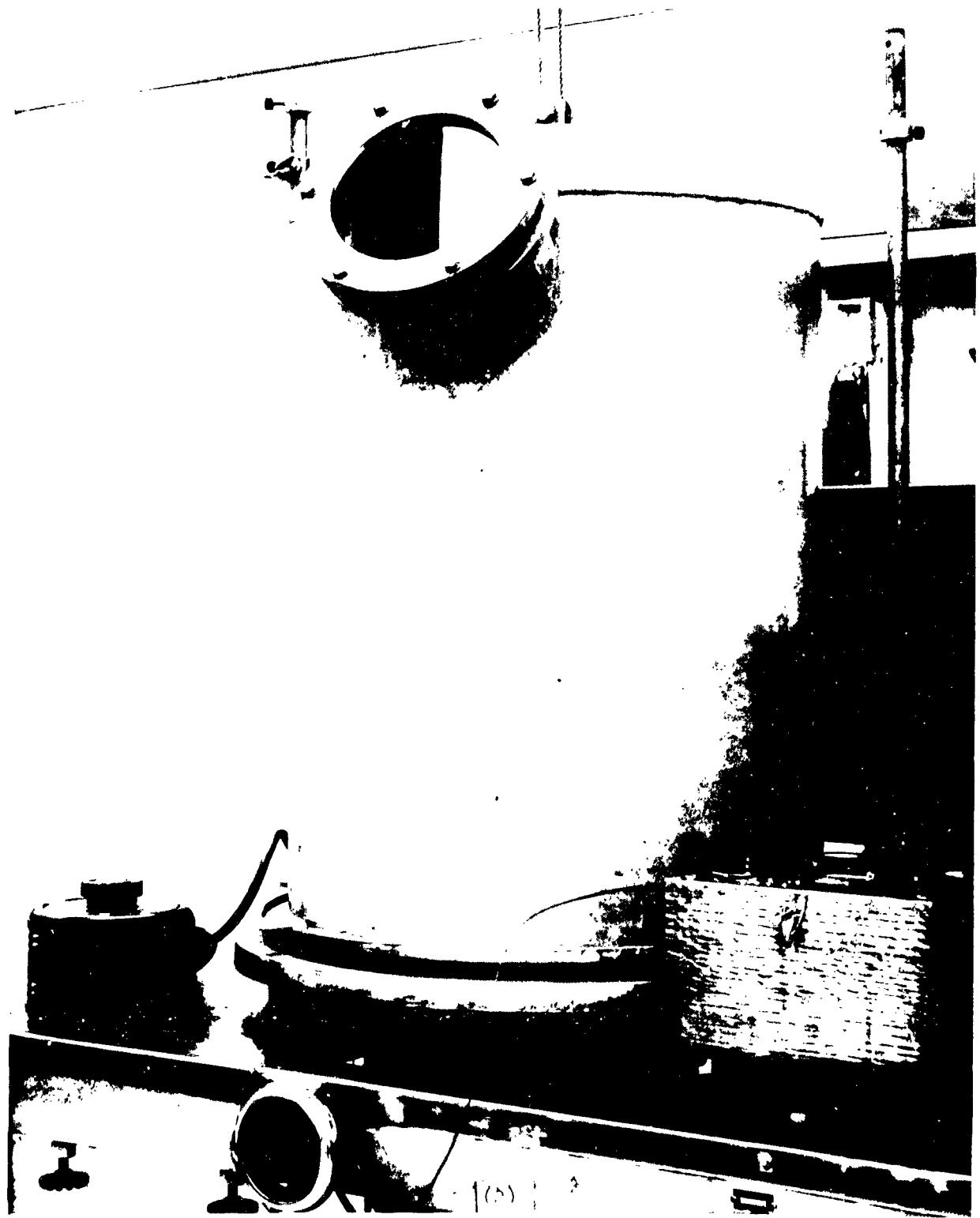


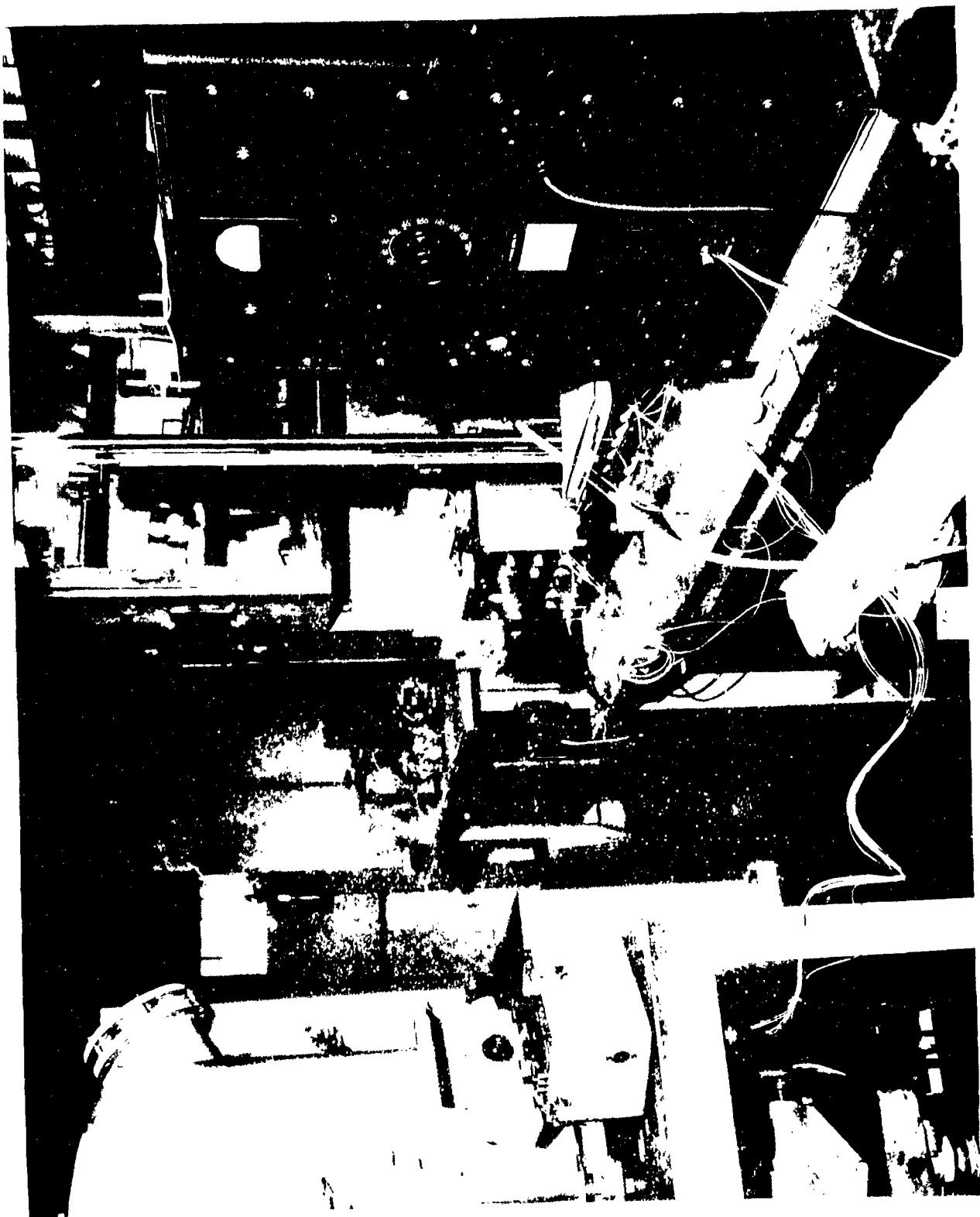
.250 conductor spacing

.250 conductor width

Figure 5.







REFERENCES

- (a) NAFI Materials Test Report No. 14-57
- (b) NAFI Materials Test Report No. 81-59
- (c) NAFI Materials Test Report No. 50-60
- (d) NAFI Materials Test Report No. 93-61
- (e) MIL-STD-275
- (f) MIL-STD-446
- (g) MIL-E-5400
- (h) BuWeps Drawing No. AV 1633
- (i) BuWeps Drawing No. AV 2806
- (j) BuWeps Drawing No. DS 643

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